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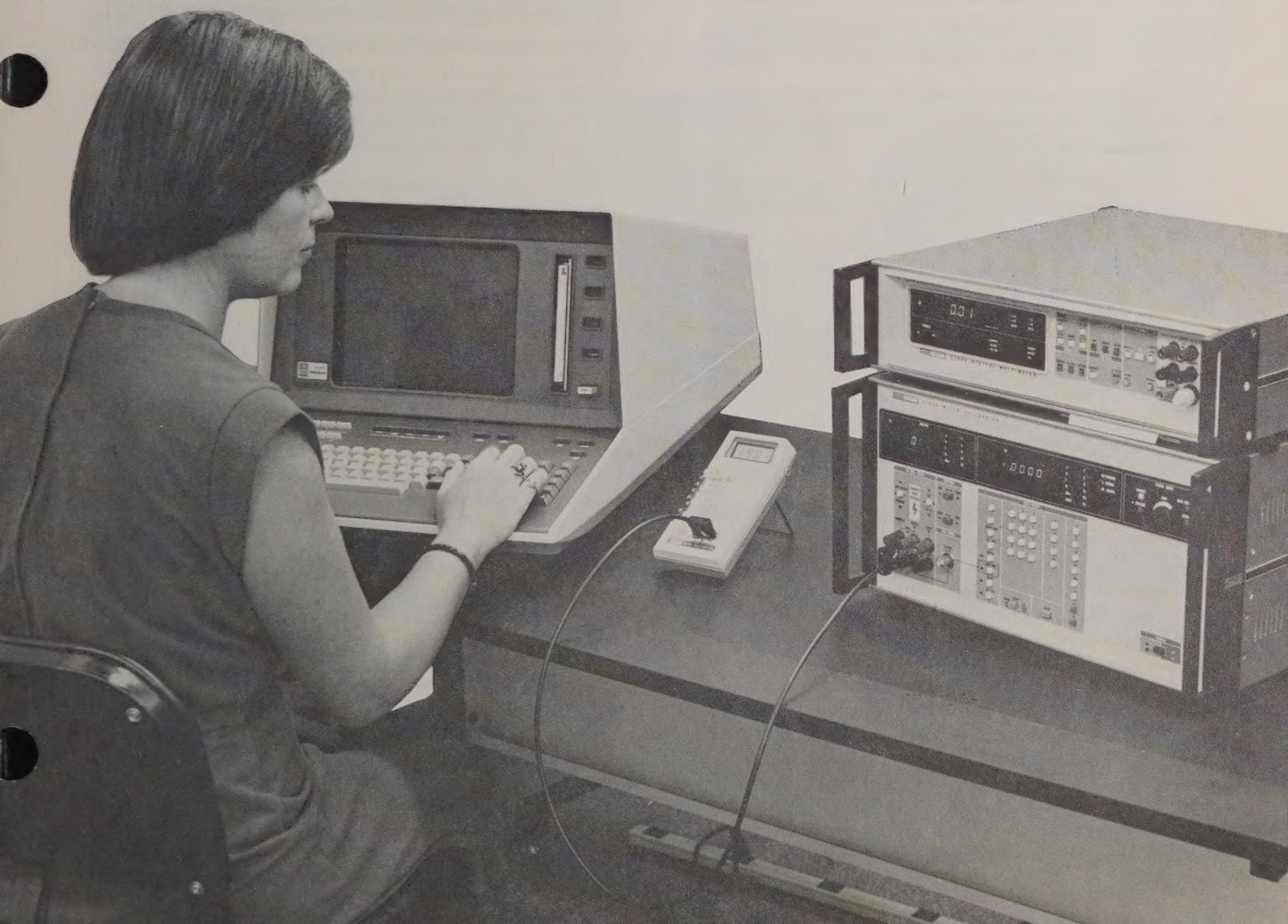
IEEE Standard 488-1975 Digital Interface For Programmable Instrumentation



With the increased complexity of todays measurement systems and the need for greater performance in the system test environment, former methods for the solution of interface problems have become undesirable. The need for implementation of a standard communication line between instruments has motivated the development of IEEE standard 488-1975. Today this document is an approved and published standard recognized throughout the instrumentation industry.

BEFORE IEEE STANDARD

The traditional approach to interface design has been to provide each device with a number of specialized control, data and status signal lines. In this way the interface design was relatively simple and straight forward. However, this resulted in as many different interface designs as there were interface designers. Also for each design to take advantage of different codes, formats, signal levels, etc., a special purpose interface adapter was required. All this resulted in large interface systems becoming extremely complex and costly. Of course such complex systems were also difficult to maintain and in most cases required a trained operator.

BENEFITS OF SYSTEM APPROACH

In most test environments a decision between increased manpower and semi-automated system test capability must be made. Any such decision will be based on an analysis of accured benefits vs. cost. The systems approach provides many advantages, a few of which are:

- A system is not vulnerable to operator fatigue and, therefore, provides more consistent results in repetitive situations.
- Being generally much faster, systems provide greater throughput.
- Test systems can be designed which vary the testing parameters based upon results obtained in previous tests - thus adaptive data acquisition.
- Automated systems can usually perform more thorough tests.
- Formatted results can be obtained directly or developed within the system. This allows for a more efficient data handling capability.
- Accuracy is generally enhanced by a reduction in the human error factor and system errors can be adjusted and compensated out of final results.

CONSIDERATIONS OF INSTRUMENTATION SYSTEMS

The requirements of system implementations in the most broad sense are many and varied. Instrumentation systems may range from a simple lab bench mini-system to an entire industrial plant monitoring function. Each application has its own specific requirements, therefore any standard instrumentation philosophy requires a great many considered compromises. For instance, the total number of interconnected instruments may differ greatly depending on the size of the measurement system. Some systems, once assembled, remain intact indefinitely whereas others may only be used for a few hours then dismantled. Most systems require short data transmission paths, others may require remote data entry from terminals. Data rates can be as varied as the types of devices interconnected and noise environments vary with the application.

With these widely non-uniform system requirements in mind, it may be wondered whether any interface system would be suitable.

CONSIDERATIONS OF IEEE-488 SYSTEMS

The IEEE-488 interface definition focuses upon the most commonly accepted needs and the absolutely required objectives of all interfaces. As such the following parameters were formulated for IEEE-488 interface implementation. The interface shall provide shielded cable interconnection with high drive capability so that it may have high noise immunity. Data rates shall be under one megabyte with typical operation much lower. Interconnection shall be less than twenty meters and no more than fifteen devices shall comprise the system. Typical message transfer is 10 to 20 characters.

IEEE-488 SPECIFICATIONS

In general the definition of any interface system can be divided into three broad catagories; mechanical, electrical, and functional.

The mechanical portion of the interface defines the physical configuration of the cables and connectors.

The electrical portion covers all those aspects of the interface operation concerned with the actual transfer of data via the interface connection.

Finally the functional aspects of the interface are concerned with the protocol of the data transferred over the interface, and the nature and meaning of the communicated information.

MECHANICAL SPECIFICATIONS

The basic considerations governing the mechanical specifications of the interface come from the requirements that the distances between devices be limited; that a bus structure is to be implemented; and the connector mounting space is small.

The cable assembly provided for in the standard requires that it be no more than four meters in length with both a plug and receptacle connector at both ends. This allows for stacking and linear bus configuring. The connector is a 24 pin, D-type with provisions for locking screws.

ELECTRICAL SPECIFICATIONS

The IEEE-488 standard interface provides for a bus type interconnection method. This is opposed to a star type connection in which all connections originate from one device. Bus type structure implies a parallel nature to all signal lines contained in the connection. This allows linear daisy chain connection from device to device so that no one device is required to handle all interconnects.

Messages may be coded on one or a set of signal lines as determined by the message content. The total 16 lines are divided into 8 data and 3 control signals. A message transferred over the data lines is transmitted in a byte serial-bit parallel manner using a 3 wire handshake.

As stated, the maximum data rate for the bus is one megabyte per sec, however, in most cases data rates will not exceed 250k bytes without hardware modification. Each interface configuration will require the consideration of the relationships between the system performance and the specific devices used to implement that performance. An example: a standard performance bus will operate at distances up to 20 meters, at a maximum of 250k bytes per second, with an equivalent standard load every 2 meters. The interface is not specified to

operate correctly with more than 20 meters of interconnecting cable used in the entire system. This limitation is the result of the distribution system selected for the interface bus. Ideal design for transmission line termination would call for a lump termination but this would maximize the system configuring task. Instead, a compromise was made to provide for distributed terminations and restrict the number of devices on the bus at one time to 15.

FUNCTIONAL SPECIFICATIONS

The simplest system configuration consists of one device communicating directly with another device. In this mode no controller instrument is required. Data transfer is limited to direct transfer between one device manually set to "talk only" and one or more devices manually set to "listen only". The full flexibility of the system is best utilized when a controlling instrument is interconnected. The controller basically acts as traffic manager with data handling capability. It is the controller that commands devices to talk or listen over the IEEE bus.

At any one time, any particular instrument connected to the bus may be either idle, simply monitoring the activity on the bus, or it may be functioning as a talker or listener or controller. As a talker, it sends data over the bus to a listener or listeners. As a listener, it receives such data. As a controller, it directs the flow of data on the bus, mainly by designating which instruments are to send data and which are to receive data. An instrument may be equipped to serve in more than one of these interface roles, depending on the kind of system expected to be built around it.

All of the active circuitry equipping an instrument to talk, listen, control or simply to monitor the bus is contained within that instrument. The interconnecting bus is entirely passive. Circuitry and bus together make up the interface.

To address an instrument, the controller uses seven of the eight data-bus lines. This allows instruments using the ASCII 7-bit code to act as controllers. As shown in Table I, five data bits are available for addresses, so a total of 31 addresses is available in one byte.

Table 1. Command and Address Codes

Code Form								Meaning
X	0	0	A_5	A_4	A_3	A_2	A_1	Universal Commands
X	0	1	L_5	L_4	L_3	L_2	L_1	Listen Address
X	0	1	1 except	1	1	1	1	Unlisten Command
X	1	0	T_5	T_4	T_3	T_2	T_1	Talk Address
X	1	0	1	1	1	1	1	Untalk Command
X	1	1	S_5	S_4	S_3	S_2	S_1	Secondary Commands
X	1	1	1 except	1	1	1	1	Ignored
Code used when attention (ATN) is true (low)								

A talk address selects one instrument to send data and disables all the others with talker circuity from sending data. That is, sending a talk address selects one and only one instrument to transmit on the data bus, preventing data errors due to wire OR'ing on the data bus. A listen address selects one instrument

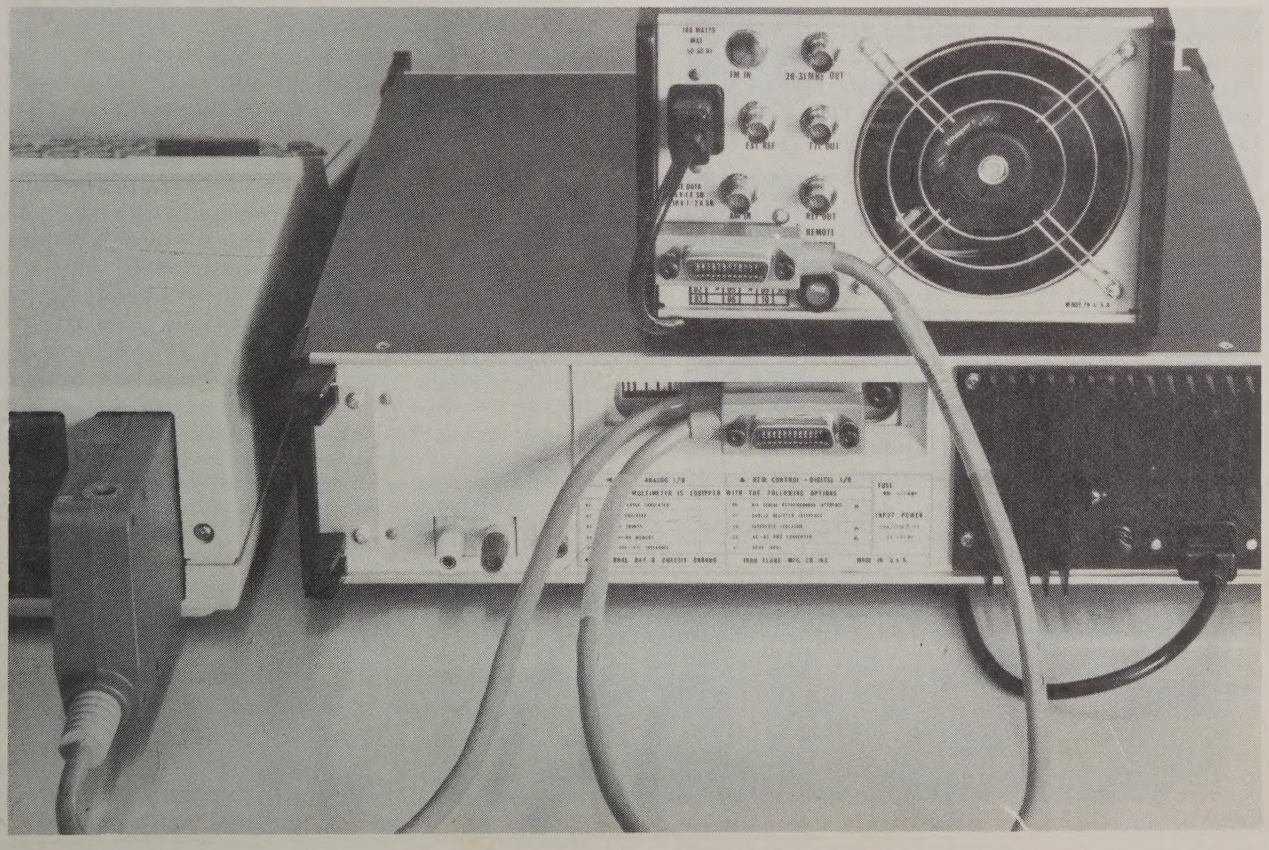


Figure 1. IEEE-488 Cabling Interconnection. The design of the IEEE interface cable allows both stacked (parallel) or linear connection in one system.

to receive data but does not affect the others — they remain as they were addressed or unaddressed. Thus, several instruments may listen at the same time. Sending a talk address does not affect listeners or vice versa.

Also shown in Table I are two other commands associated with the addressing process—the untalk and unlisten commands. They are called "un" commands because they perform exactly the opposite function of an address; that is, they disable an instrument from sending or receiving data. The unlisten command is used whenever a new listener or group of listeners is to be selected in order to disable all the previously selected listeners. The untalk command disables all previously selected talkers. In fact, the untalk command is merely a talk address using an address number to which no instrument may be assigned, and instruments make no distinction between an untalk command and a talk address to a different device.

During the configuration of a system, each device must be assigned one or more addresses unique to it. However, two listeners may have the same address if they are always to receive the same data. An instrument is assigned its address by some convenient means such as switches on the rear panel or jumper wires on a printed-circuit board. Typically, there are five switches or jumpers to be set which specify the five bits of the talk or listen address (or both if the instrument is both a talker and a listener). The particular setting of the address is the system designer's choice.

Bus Lines

Sixteen lines are used to communicate on the IEEE bus. Eight of these lines are the "data bus" which carries multibyte messages to and from devices. Three other lines called the "handshake" lines actually control the manner in which the data bus transfers data. The other five lines are called interface management signals. Their use generally imparts some immediate action within the interface or flags a condition existing within the interface. A brief description of each of the eight control lines follows.

Handshake Lines

- DAV(data valid) is used to indicate the condition (availability and validity) of information on the DIO (Data Input/Output) signal lines.

- NRFD (not ready for data) is used to indicate the condition of readiness of device(s) to accept data.

- NDAC (not data accepted) is used to indicate the condition of acceptance of data by device(s).

Interface Management Lines

- ATN (attention) is used to specify how data on the DIO signal lines is to be interpreted and which devices must respond to the data.

- IFC (interface clear) is used to place the interface system, portions of which are contained in all interconnected devices, in a known quiescent state.

- SRQ (service request) is used by a device to indicate the need for attention and to request an interruption of the current sequence of events.

- REN (remote enable) is used (in conjunction with other messages) to select between two alternate sources of device programming data.

- EOI (end or identify) is used to indicate the end of a multiple byte transfer sequence or, in conjunction with ATN, to execute a polling sequence.

Handshake For Data Transfer

Transfer of each data byte on the DIO signal lines is accomplished via a set of three signal lines; DAV (data valid), NRFD (not ready for data), and NDAC (not data accepted). These signals operate in an interlocked handshake mode. Two signal lines, NRFD and NDAC, are each connected in a logical AND (wire OR) to all devices connected to the interface. The DAV signal is sent by the talker and received by potential listeners whereas the NRFD and NDAC signals are sent by potential listeners and received by the talker. When all potential listeners have acknowledged they are "ready for data" via NRFD the talker initiates the data byte transfer by signaling data is valid on DAV. Upon receiving the DAV message the device removes its RFD message and asserts the "data accepted" message on NDAC. If only one device on the bus is an active listener the existence of the DAC message alerts the talker that the data byte has been received and may be removed from the bus. When two or more devices are "listening", the situation during the address operation, each device participates in the same handshake cycle. The major difference, however, is that each step of the handshake cycle is not completed until *all* devices have completed a particular step in the process. DAV is not sent until all devices are ready. A new data byte is not sent until all devices, from the fastest to the slowest, have accepted the previous data byte. This process enables devices with different data acceptance or response rates to co-exist on the

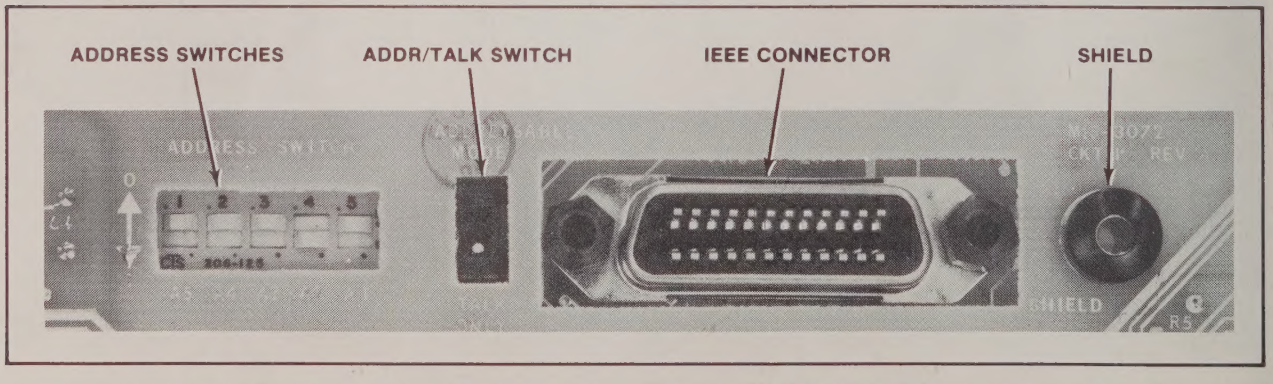


Figure 2. Address Switches. Shown are the addressing switches on the 8500 DVM. Note that a Talk Only switch is provided in the same switch assembly.

THE IEEE-488 BUS

The IEEE Interface Bus transfers data and commands between the components of an instrumentation system on 16 signal lines. The interface functions for each system component are performed within the component so only passive cabling is needed to connect the system. The cables connect all instruments, controllers, and other components of the system in parallel to the signal lines.

Eight of the lines (DIO1-DIO8) are reserved for the transfer of data and other messages in a byte-serial, bit-parallel manner. Data and message transfer is asynchronous, coordinated by the three handshake lines (DAV, NRFD, NDAC). The other five lines are for control of bus activity.

Devices connected to the bus may be talkers, listeners, or controllers. The controller dictates the role of each of the other devices by setting the ATN (attention) line true and sending talk or listen addresses on the data lines (DIO1-DIO8). Addresses are set into each device at the time of system configuration either by switches built into the device or by jumpers on a PC board. While the ATN line is true, all devices must listen to the data lines. When the ATN line is false, only devices that have been addressed will actively send or receive data. All others ignore the data lines.

Several listeners can be active simultaneously but only one talker can be active at a time. Whenever a talk address is put on the data lines (while ATN is true), all other talkers will be automatically unaddressed.

Information is transmitted on the data lines under sequential control of the three handshake lines. No step in the sequence can be initiated until the previous step is completed. Information transfer can proceed as fast as devices can respond, but no faster than allowed by the slowest device presently addressed as active. This permits several devices to receive the same message byte concurrently.

The ATN line is one of the five control lines. When ATN is true, addresses and universal commands are transmitted on only seven of the data lines using the ASCII code*. When ATN is false, any code of 8 bits or less understood by both talker and listener(S) may be used.

The other control lines are IFC, REN, SRQ, EOI.

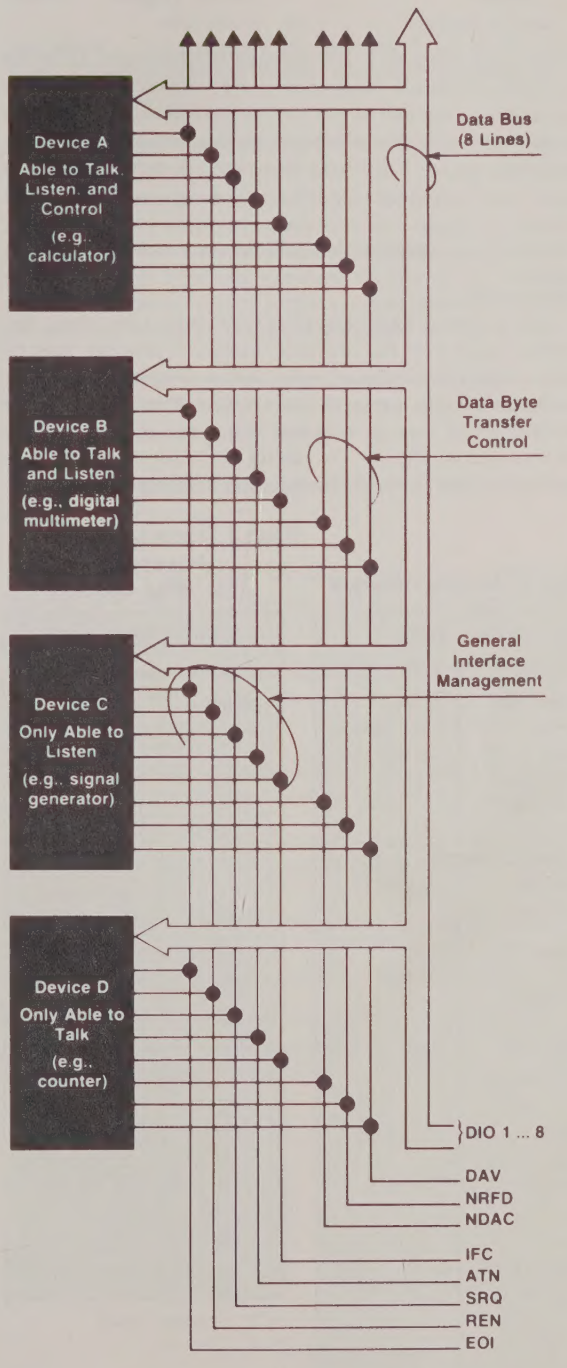
IFC (interface clear) places the interface system in a known quiescent state.

REN (remote enable) is used with other coded messages to select either local or remote control of each device.

Any active device can set the SRQ (service request) line true. This indicates to the controller that some device on the bus wants attention, say a counter that has just completed a time-interval measurement and wants to transmit the reading to a printer.

EOI (end or identify) is used by a device to indicate the end of a multiple-byte transfer sequence. When a controller sets both the ATN and EOI lines true, each device capable of a parallel pole indicates its current status on the DIO line assigned to it.

In the interest of cost-effectiveness it is not necessary for every device to be capable of responding to all the lines. Each can be designed to respond only to those lines that are pertinent to its function on the bus.



same bus. Data is transferred asynchronously at the rate of the slowest listener participating in the conversation. High speed data transfer between two devices is not affected adversely by slow speed devices physically connected to the bus, when these slower devices are not addressed to participate in the conversation.

Functions

The functional aspects of the interface definition are concerned with the content of the messages sent over the interface. Each function performed by the interface does so within a precisely defined protocol arrangement. The ten possible interface functions that can be implemented are:

1. Source Handshake
2. Acceptor Handshake
3. Talker
4. Listener
5. Service Request
6. Remote/Local
7. Parallel Poll
8. Device Clear
9. Device Trigger
10. Controller

The interface designer is not required to implement all of the possible interface functions. For example, a non-programmable counter would only communicate as a talker on the bus and would therefore be required to implement only the talker and source handshake functions. A printer acts as a listener and could be implemented using only listen and acceptor functions. Any device must implement either a talker, a listener, or a controller function or any combination of the three.

MESSAGES

Basically there are two types of messages that are communicated over the interface system. A message may be either an *interface message* or a *device dependent message*. Interface messages perform some action directly within the interface which may or may not affect the operation of the interconnected device. A device dependent message is specifically constructed by the interface designer to affect some action directly in the device that the message is communicated to. For example, a string of characters sent to control the range setting of an instrument are device dependent messages. Note that these messages are defined by the instrument interface designer. Interface messages, however, are predefined. These are the messages that, among other things, allow a device to be made a talker or a listener. The IEEE-488 standard has agreed upon a uniform nomenclature for these messages. An example is MLA which is "my listen address". There are about 25 defined interface messages listed in the IEEE-488 standard. Table 2 details several interface messages. Table 3 details a device dependent message.

The most important distinction between these two types of messages is the state of the attention signal. Interface messages are sent exclusively by a controller device and therefore all such messages are transmitted with the ATN signal in the true state. In this way all devices connected on the bus will listen to all interface messages. On the other hand, device dependent messages are sent with the ATN signal false. These messages may be programming data sent to an instrument to set up measurement or it may be the numerical data returning the results of the measurement. Table 4 presents a typical programming sequence.

Table 2. Interface Messages

ATN = TRUE	
Message	**Data**
MLA (My listen address)	X0 1LL LLL
MTA (My talk address)	X1 0TT TTT
UNT (Untalk)	X1 011 111
UNL (Unlisten)	X0 111 111
SPE (Serial poll enable)	X0 011 000
SPD (Serial poll disable)	X0 011 001
GTL (Go to local)	X0 000 001

X - 1 or 0 (Don't Care)
L - Listen address
T - Talk address

Table 3. Device Dependent Messages (For 1953A Counter)

ATN = FALSE	
Message	**Data**
F	01 000 110
0	00 110 000
R	01 010 011
5	00 110 101
0	00 110 000
0	00 110 000
0	00 110 000
0	00 110 000
1	00 110 001
0	00 110 000
0	00 110 000
0	00 110 000
.	00 101 110
0	00 110 000
E	01 000 101
+	00 101 011
6	00 110 110
CR*	00 001 101
LF*	00 001 010

*CR - Carriage Return
*LF - Line Feed

Table 4. Typical Programming Sequence

Message	Data	Message Type I-Interface D-Device dependent	Explanation
UNL	X0 111 111	I	Send an unlisten command to all devices.
MLA	X0 100 010	I	Send listen command to all devices. Only addressed device becomes listener (In this case device 2).
V	01 010 110	D	Send programming data to the 8500A addressed as listener.
R	01 010 010	D	
1	00 110 001	D	
F	01 000 110	D	
?	00 111 111	D	
MTA	X1 000 010	I	Make device 2 a talker by sending out talk address on bus.
+	00 101 011	D	
1	00 110 001	D	Device 2 is a talker and responds with measurement data.
.	00 101 110	D	
0	00 110 000	D	
1	00 110 001	D	
8	00 111 000	D	
1	00 110 001	D	
5	00 110 101	D	
9	00 111 001	D	
E	01 000 101	D	
+	00 101 011	D	
0	00 110 000	D	
CR	00 001 101	D	
LF	00 001 010	D	
UNL	X0 111 111	I	All devices unlistened.
MLA	X0 100 100	I	New listener is addressed.

X - 1 or 0 (Don't Care)

GLOSSARY OF TERMS

ASCII. American Standard Code for Information Interchange. A coding of all letters and numbers and several special characters so that they may each be represented as one combination of eight binary bits or 3 octal digits.

bidirectional bus. A bus used by any individual device for two-way transmission of messages, that is, both input and output.

bit-parallel. Refers to a set of concurrent data bits present on a like number of signal lines used to carry information. Bit-parallel data bits may be acted upon concurrently as a group (byte) or independently as individual data bits.

bus. A signal line or a set of signal lines used by an interface system to which a multiplicity of devices are connected and over which messages are carried.

byte. A group of adjacent binary digits operated on as a unit and usually shorter than a computer word (frequently connotes a group of eight bits).

byte-serial. A sequence of bit-parallel data bytes used to carry information over a common bus.

handshake cycle. The process whereby digital signals effect the transfer of each data byte across the interface by means of an interlocked sequence of status and control signals. Interlocked denotes a fixed sequence of events in which one event in the sequence must occur before the next event may occur.

high state. The relatively more positive signal level used to assert a specific message content associated with one of two binary logic states.

interface. A shared boundary between a considered system and another system, or between parts of a system, through which information is conveyed.

interface system. The device-independent mechanical, electrical, and functional elements of an interface necessary to effect communication among a set of devices. Cables, connector, driver and receiver circuits, signal line descriptions, timing and control conventions, and functional logic circuits are typical interface system elements.

local control. A method whereby a device is programmable by means of its local (front or rear panel) controls in order to enable the device to perform different tasks. (Also referred to as manual control).

low state. The relatively less positive signal level used to assert a specific message content associated with one of two binary logic states.

programmable. That characteristic of a device that makes it capable of accepting data to alter the state of its internal circuitry to perform two or more specific tasks.

programmable measuring apparatus. A measuring apparatus that performs specified operations on command from the system and, if it is a measuring apparatus proper, may transmit the results of the measurement(s) to the system.

remote control. A method whereby a device is programmable via its electrical interface connection in order to enable the device to perform different tasks.

signal. The physical representation which conveys data from one point to another.

signal level. The magnitude of a signal when considered in relation to an arbitrary reference magnitude (voltage in the case of the IEEE standard).

signal line. One of a set of signal conductors in an interface system used to transfer messages among interconnected devices.

signal parameter. That parameter of an electrical quantity whose values or sequence of values convey information.

system. A set of interconnected elements constituted to achieve a given objective by performing a specified function.

terminal unit. An apparatus by means of which a connection (and translation, if required) is made between the considered interface system and another external interface system.

unidirectional bus. A bus used by any individual device for one-way transmission of messages only, that is, either input only or output only.

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John Fluke Mfg. Co., Inc.
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